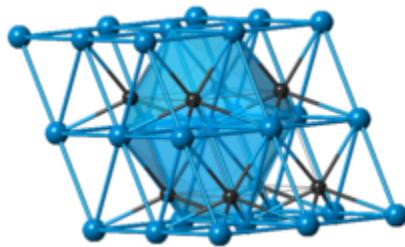


Tungsten carbide

Tungsten carbide (chemical formula: WC) is a [chemical compound](#) (specifically, a [carbide](#)) containing equal parts of [tungsten](#) and [carbon](#) atoms. In its most basic form, tungsten carbide is a fine gray powder, but it can be pressed and formed into shapes through sintering for use in [industrial machinery](#), [cutting tools](#), [chisels](#), abrasives, [armor-piercing shells](#) and [jewelry](#).

Tungsten carbide



Names

IUPAC name

Tungsten carbide

Other names

Tungsten(IV) carbide

Tungsten tetracarbide

Identifiers

CAS Number	12070-12-1 (https://commonchemistry.cas.org/detail?cas_rn=12070-12-1) ✓
3D model (JSmol)	(W ⁺ ≡C ⁻): Interactive image (https://chemapps.stolaf.edu/jmol/jmol.php?model=%5BC-%5D%23%5BW%2B%5D)
ChemSpider	2006424 (https://www.chemspider.com/Chemical-Structure.2006424.html)
ECHA InfoCard	100.031.918 (https://echa.europa.eu/substance-information/-/substanceinfo/100.031.918)
EC Number	235-123-0
PubChem CID	2724274 (https://pubchem.ncbi.nlm.nih.gov/compound/2724274) (W ⁺ ≡C ⁻)
RTECS number	Y07250000
UNII	PKZ44S724L (https://fdasis.nlm.nih.gov/srs/srsdirect.jsp?regno=PKZ44S724L) ✓
UN number	3178
CompTox Dashboard (EPA)	DTXSID4029305 (https://comptox.epa.gov/dashboard/DTXSID4029305)

InChIInChI=1S/C.W/q-1;+1 Key: UONOETXJSWQNOL-UHFFFAOYSA-N **SMILES**(W⁺≡C⁻): [C-]#[W+]**Properties**

Chemical formula	WC
Molar mass	195.85 g·mol ⁻¹
Appearance	Grey-black lustrous solid
Density	15.63 g/cm ³ ^[1]
Melting point	2,785–2,830 °C (5,045–5,126 °F; 3,058–3,103 K) ^{[3][2]}
Boiling point	6,000 °C (10,830 °F; 6,270 K) at 760 mmHg ^[2]
Solubility in water	Insoluble
Solubility	Soluble in HNO ₃ , HF ^[3]
Magnetic susceptibility (χ)	1·10 ⁻⁵ cm ³ /mol ^[3]
Thermal conductivity	110 W/(m·K) ^[4]

Structure

Crystal structure	Hexagonal, hP2 ^[5]
Space group	P $\bar{6}$ m2, No. 187 ^[5]
Point group	$\bar{6}$ m2 ^[5]
Lattice constant	$a = 2.906 \text{ \AA}$, $c = 2.837 \text{ \AA}$ ^[5] $\alpha = 90^\circ$, $\beta = 90^\circ$, $\gamma = 120^\circ$
Molecular shape	Trigonal prismatic (center at C) ^[6]

Thermochemistry

Heat capacity (C)	39.8 J/(mol·K) ^[4]
-------------------	-------------------------------

Std molar entropy (S^\ominus_{298})	32.1 J/mol·K
Related compounds	
Other anions	Tungsten boride Tungsten nitride
Other cations	Molybdenum carbide Titanium carbide Silicon carbide
Except where otherwise noted, data are given for materials in their standard state (at 25 °C [77 °F], 100 kPa).	
X verify (https://en.wikipedia.org/w/index.php?title=Special:ComparePages&rev1=452024347&page2=Tungsten+carbide) (what is ✓ ✗ ?)	
Infobox references	

Tungsten carbide is approximately twice as stiff as [steel](#), with a [Young's modulus](#) of approximately 530–700 GPa, [\[4\]](#)[\[7\]](#)[\[8\]](#)[\[9\]](#) and is double the density of [steel](#)—nearly midway between that of [lead](#) and [gold](#). It is comparable with [corundum](#) (α - Al_2O_3) in [hardness](#) and can be polished and finished only with abrasives of superior hardness such as [cubic boron nitride](#) and diamond powder, wheels and compounds.

Naming

Historically referred to as [Wolfram](#), [Wolf Rahm](#), [wolframite](#) ore was then later carburized and cemented with a binder creating a composite now called "tungsten carbide". [\[10\]](#) Tungsten is Swedish for "heavy stone".

Colloquially among workers in various industries (such as [machining](#)), tungsten carbide is often simply called [carbide](#).

Synthesis

Tungsten carbide is prepared by reaction of tungsten metal and carbon at 1,400–2,000 °C. [\[11\]](#) Other methods include a lower temperature fluid bed process that reacts either tungsten metal or blue WO_3 with CO/CO_2 mixture and H_2 between 900 and 1,200 °C. [\[12\]](#)

WC can also be produced by heating WO_3 with [graphite](#): directly at 900 °C or in hydrogen at 670 °C following by [carburization in argon](#) at 1,000 °C.^[13] [Chemical vapor deposition](#) methods that have been investigated include:^[11]

- reacting [tungsten hexachloride](#) with hydrogen (as a [reducing agent](#)) and [methane](#) (as the source of carbon) at 670 °C (943 K)
$$\text{WCl}_6 + \text{H}_2 + \text{CH}_4 \rightarrow \text{WC} + 6\text{HCl}$$
- reacting [tungsten hexafluoride](#) with hydrogen (as reducing agent) and [methanol](#) (as source of carbon) at 350 °C (623 K)
$$\text{WF}_6 + 2\text{H}_2 + \text{CH}_3\text{OH} \rightarrow \text{WC} + 6\text{HF} + \text{H}_2\text{O}$$

Chemical properties

There are two well-characterized compounds of tungsten and carbon, WC and [tungsten semicarbide](#), W_2C . Both compounds may be present in coatings and the proportions can depend on the coating method.^[14]

Another meta-stable compound of tungsten and carbon can be created by heating the WC phase to high temperatures using plasma, then quenching in inert gas (plasma spheroidization).^[15] This process causes macrocrystalline WC particles to spheroidize and results in the non-stoichiometric high temperature phase WC_{1-x} existing in a meta-stable form at room temperature. The fine microstructure of this phase provides high hardness (2800-3500 HV) combined with good toughness when compared with other tungsten carbide compounds. The meta-stable nature of this compound results in reduced high temperature stability.

At high temperatures WC decomposes to tungsten and carbon and this can occur during high-temperature [thermal spray](#), e.g., in high velocity oxygen fuel (HVOF) and high energy plasma (HEP) methods.^[16]

[Oxidation](#) of WC starts at 500–600 °C (773–873 K).^[11] It is resistant to [acids](#) and is only attacked by [hydrofluoric acid/nitric acid](#) (HF/HNO₃) mixtures above room temperature.^[11] It reacts with [fluorine](#) gas at room temperature and [chlorine](#) above 400 °C (673 K) and is unreactive to dry H₂ up to its melting point.^[11] Finely powdered WC oxidizes readily in [hydrogen peroxide](#) aqueous solutions.^[17] At high temperatures and pressures it reacts with aqueous [sodium carbonate](#) forming [sodium tungstate](#), a procedure used for recovery of scrap cemented carbide due to its selectivity.

Physical properties

Tungsten carbide has a high melting point at 2,870 °C (3,140 K), a boiling point of 6,000 °C (6,270 K) when under a pressure equivalent to 1 standard atmosphere (101.325 kilopascals),^[2] a thermal conductivity of 110 W·m⁻¹·K⁻¹,^[4] and a coefficient of thermal expansion of 5.5 μm·m⁻¹·K⁻¹.^[7]

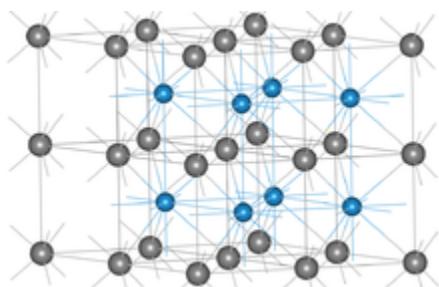
Tungsten carbide is extremely hard, ranking about 9 to 9.5 on the Mohs scale, and with a Vickers number of around 2600.^[8] It has a Young's modulus of approximately 530–700 GPa,^{[4][7][8][9]} a bulk modulus of 630–655 GPa, and a shear modulus of 274 GPa.^[18] It has an ultimate tensile strength of 344 MPa,^[9] an ultimate compression strength of about 2.7 GPa and a Poisson's ratio of 0.31.^[18]

The speed of a longitudinal wave (the speed of sound) through a thin rod of tungsten carbide is 6220 m/s.^[19]

Tungsten carbide's low electrical resistivity of about 0.2 μΩ·m is comparable with that of some metals (e.g. vanadium 0.2 μΩ·m).^{[11][20]}

WC is readily wetted by both molten nickel and cobalt.^[21] Investigation of the phase diagram of the W-C-Co system shows that WC and Co form a pseudo binary eutectic. The phase diagram also shows that there are so-called η-carbides with composition (W,Co)₆C that can be formed and the brittleness of these phases makes control of the carbon content in WC-Co cemented carbides important.^[21] In the presence of a molten phase such as cobalt, abnormal grain growth is known to occur in the sintering of tungsten carbide, with this having significant effects on the performance of the product material.

Structure



a-WC structure, carbon atoms are gray.^[5]

There are two forms of WC, a [hexagonal](#) form, α -WC ([hP2](#), space group $P\bar{6}m2$, No. 187),^{[5][6]} and a [cubic](#) high-temperature form, β -WC, which has the [rock salt structure](#).^[22] The hexagonal form can be visualized as made up of a simple hexagonal lattice of metal atoms of layers lying directly over one another (i.e. not close packed), with carbon atoms filling half the interstices giving both tungsten and carbon a regular trigonal prismatic, 6 [coordination](#).^[6] From the unit cell dimensions^[23] the following bond lengths can be determined: the distance between the tungsten atoms in a hexagonally packed layer is 291 pm, the shortest distance between tungsten atoms in adjoining layers is 284 pm, and the tungsten carbon bond length is 220 pm. The tungsten–carbon bond length is therefore comparable to the single bond in $W(CH_3)_6$ (218 pm) in which there is strongly distorted trigonal prismatic coordination of tungsten.^[24]

Molecular WC has been investigated and this gas phase species has a bond length of 171 pm for $^{184}W^{12}C$.^[25]

Applications

Cutting tools for machining



Cemented carbide drill and end mills

Sintered tungsten carbide–cobalt [cutting tools](#) are very abrasion resistant and can also withstand higher temperatures than standard [high-speed steel](#) (HSS) tools. Carbide cutting surfaces are often used for [machining](#) tough materials such as [carbon steel](#) or [stainless steel](#), and in applications where steel tools would wear quickly, such as high-quantity and high-precision production. Because carbide tools maintain a sharp cutting edge better than steel tools, they generally produce a better finish on parts, and their temperature resistance allows faster machining. The material is usually called [cemented carbide](#), solid carbide, hardmetal or

tungsten-carbide cobalt. It is a metal matrix composite, where tungsten carbide particles are the aggregate, and metallic [cobalt](#) serves as the matrix. [\[26\]](#)[\[27\]](#)

Ammunition

Tungsten carbide, in its monolithic sintered form, or much more often in cemented tungsten carbide cobalt composite (see above), is often used in [armor-piercing ammunition](#), especially where [depleted uranium](#) is not available or is politically unacceptable. W_2C projectiles were first used by German [Luftwaffe](#) tank-hunter squadrons in [World War II](#). However, owing to the limited German reserves of tungsten, W_2C material was reserved for making machine tools and small numbers of [projectiles](#). It is an effective penetrator due to its combination of great hardness and very high density. [\[28\]](#)[\[29\]](#)

Tungsten carbide ammunition is now generally of the [sabot](#) type. SLAP, or [saboted light armour penetrator](#), where a plastic sabot discards at the barrel muzzle, is one of the primary types of sabotaged small arms ammunition. Non-discarding jackets, regardless of the jacket material, are not perceived as sabots but as bullets. Both of the designs are, however, common in designated light armor-piercing small arms ammunition. Discarding sabots such as are used with M1A1 Abrams main gun are more commonplace in precision high-velocity gun ammunition. [\[30\]](#)[\[31\]](#)

Mining and foundation drilling



A tricone roller cone assembly from a raiseboring reamer, showing the protruding tungsten carbide buttons inset into the rollers

Tungsten carbide is used extensively in mining in top hammer rock drill bits, [downhole hammers](#), [roller-cutters](#), [long wall plough chisels](#), [long wall shearer picks](#), [raiseboring](#) reamers, and [tunnel boring machines](#). In these applications it is also used for wear and corrosion resistant components in inlet control for well screens, sub-assemblies, seal rings and bushings common in oil and gas drilling. ^[32] It is generally utilised as a button insert, mounted in a surrounding matrix of steel that forms the substance of the bit. As the tungsten carbide button is worn away the softer steel matrix containing it is also worn away, exposing yet more button insert.

Nuclear

Tungsten carbide is also an effective [neutron reflector](#) and as such was used during early investigations into nuclear chain reactions, particularly for weapons. A criticality accident occurred at [Los Alamos National Laboratory](#) on 21 August 1945 when Harry Daghlian accidentally dropped a tungsten carbide brick onto a [plutonium](#) sphere, known as the [demon core](#), causing the [subcritical mass](#) to go supercritical with the reflected [neutrons](#).

Sports usage



A [Nokian](#) bicycle tire with tungsten carbide spikes. The spikes are surrounded by aluminum.

Trekking poles, used by many [hikers](#) for balance and to reduce pressure on leg joints, generally use carbide tips in order to gain traction when placed on hard surfaces (like rock); carbide tips last much longer than other types of tip. ^[33]

While [ski pole](#) tips are generally not made of carbide, since they do not need to be especially hard even to break through layers of ice, rollerski tips usually are. [Roller skiing](#) emulates [cross country skiing](#) and is used by many skiers to train during warm weather months.

Sharpened carbide tipped spikes (known as studs) can be inserted into the drive tracks of [snowmobiles](#). These studs enhance traction on icy surfaces. Longer v-shaped segments fit into grooved rods called wear rods under each snowmobile ski. The relatively sharp carbide edges enhance steering on harder icy surfaces. The carbide tips and segments reduce wear encountered when the snowmobile must cross roads and other abrasive surfaces. [\[34\]](#)

Car, motorcycle and bicycle [tires](#) with tungsten carbide studs provide better traction on ice. They are generally preferred to steel studs because of their superior resistance to wear. [\[35\]](#)

Tungsten carbide may be used in [farriery](#), the shoeing of [horses](#), to improve traction on slippery surfaces such as roads or ice. Carbide-tipped hoof nails may be used to attach the [shoes](#); [\[36\]](#) in the United States, borium – chips of tungsten carbide in a matrix of softer metal such as [bronze](#) or mild steel – may be welded to small areas of the underside of the shoe before fitting. [\[37\]](#):⁷³

Surgical instruments & medical

Tungsten carbide is also used for making surgical instruments meant for open surgery (scissors, forceps, hemostats, blade-handles, etc.) and [laparoscopic surgery](#) (graspers, scissors/cutter, needle holder, cautery, etc.). They are much costlier than their stainless-steel counterparts and require delicate handling, but give better performance. [\[38\]](#)

Jewelry

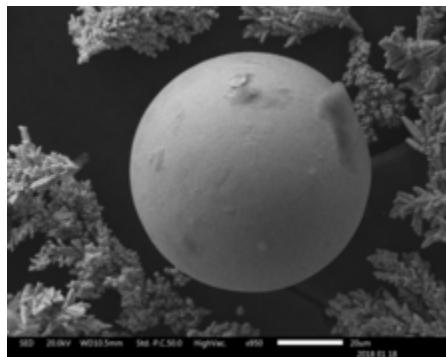


Tungsten carbide ring

Tungsten carbide, typically in the form of a cemented carbide (carbide particles [brazed](#) together by metal), has become a popular material in the bridal jewelry industry due to its extreme

hardness and high resistance to scratching.^{[39][40]} Even with high-impact resistance, this extreme hardness also means that it can occasionally be shattered under certain circumstances.^[41] Some consider this useful, since an impact would shatter a tungsten ring, quickly removing it, where precious metals would bend flat and require cutting. Tungsten carbide is roughly 10 times harder than 18k gold. In addition to its design and high polish, part of its attraction to consumers is its technical nature.^[39] Special tools, such as locking pliers, may be required if such a ring must be removed quickly (e.g. due to medical emergency following a hand injury accompanied by swelling).^[42]

Other



Spherical tungsten carbide under [scanning electron microscope](#), magnification x950, Material Laboratory

Tungsten carbide is widely used to make the rotating ball in the tips of [ballpoint pens](#) that disperse ink during writing.^[43]

Tungsten carbide is a common material used in the manufacture of [gauge blocks](#), used as a system for producing precision lengths in [dimensional metrology](#).

English guitarist [Martin Simpson](#) is known to use a custom-made tungsten carbide [guitar slide](#).^[44] The hardness, weight, and density of the slide give it superior [sustain](#) and volume compared to standard glass, steel, ceramic, or brass slides.

Tungsten carbide has been investigated for its potential use as a [catalyst](#) and it has been found to resemble [platinum](#) in its catalysis of the production of water from hydrogen and oxygen at room temperature, the [reduction](#) of [tungsten trioxide](#) by hydrogen in the presence of water, and

the [isomerisation](#) of 2,2-dimethylpropane to 2-methylbutane.^[45] It has been proposed as a replacement for the [iridium](#) catalyst in [hydrazine](#)-powered [satellite thrusters](#).^[46]

A tungsten carbide coating has been utilized on brake discs in high performance automotive applications to improve performance, increase service intervals and reduce brake dust.^[47]

Toxicity

The primary health risks associated with tungsten carbide relate to inhalation of dust, leading to [silicosis](#)-like pulmonary [fibrosis](#).^[48] Cobalt-cemented tungsten carbide is also anticipated to be a human carcinogen by the American [National Toxicology Program](#).^[49]

References

1. *"Document Failed"* (https://web.archive.org/web/20120324232529/http://gestis-en.itrust.de/nxt/gateway.dll/gestis_en/491085.xml) . Archived from the original (http://gestis-en.itrust.de/nxt/gateway.dll/gestis_en/491085.xml) on 24 March 2012. Retrieved 18 June 2018.
2. Pohanish, Richard P. (2012). *Sittig's Handbook of Toxic and Hazardous Chemicals and Carcinogens* (<https://books.google.com/books?id=RYt0Wzb60b4C&pg=PA2670>) (6th ed.). Elsevier, Inc. p. 2670. *ISBN 978-1-4377-7869-4*.
3. Haynes, William M., ed. (2011). *CRC Handbook of Chemistry and Physics* (92nd ed.). Boca Raton, FL: CRC Press. p. 4.96. *ISBN 1-4398-5511-0*.
4. Blau, Peter J. (2003). *Wear of Materials* (<https://books.google.com/books?id=2F05T8u0oQUC&pg=PA1345>) . Elsevier. p. 1345. *ISBN 978-0-08-044301-0*.
5. *Kurlov*, p. 22
6. Wells, A. F. (1984). *Structural Inorganic Chemistry* (5th ed.). Oxford Science Publications. *ISBN 0-19-855370-6*.
7. *Kurlov*, p. 3
8. Groover, Mikell P. (2010). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems* (<https://books.google.com/books?id=QU-Qvud3OvoC&pg=PA135>) . John Wiley & Sons. p. 135. *ISBN 978-0-470-46700-8*.
9. Cardarelli, François (2008). *Materials Handbook: A Concise Desktop Reference* (<https://books.google.com/books?id=PvU-qbQJq7IC&pg=PA640>) . Springer Science & Business Media. p. 640. *ISBN 978-1-84628-669-8*.

10. Helmenstine, Anne Marie. *Tungsten or Wolfram Facts* (<http://chemistry.about.com/od/elementfacts/a/tungstenwolfram.htm>) . chemistry.about.com
11. Pierson, Hugh O. (1992). *Handbook of Chemical Vapor Deposition (CVD): Principles, Technology, and Applications*. William Andrew Inc. **ISBN 0-8155-1300-3**.
12. Lackner, A. and Filzwieser A. "Gas carburizing of tungsten carbide (WC) powder" **U.S. Patent 6,447,742** (<https://patents.google.com/patent/US6447742>) (2002)
13. Zhong, Y.; Shaw, L. (2011). "A study on the synthesis of nanostructured WC-10 wt% Co particles from WO_3 , Co_3O_4 and graphite". *Journal of Materials Science*. **46** (19): 6323–6331.
Bibcode:2011JMatS..46.6323Z (<https://ui.adsabs.harvard.edu/abs/2011JMatS..46.6323Z>) .
doi:10.1007/s10853-010-4937-y (<https://doi.org/10.1007%2Fs10853-010-4937-y>) . **S2CID 137383773** (<https://api.semanticscholar.org/CorpusID:137383773>) .
14. Jacobs, L.; M. M. Hyland; M. De Bonte (1998). "Comparative study of WC-cermet coatings sprayed via the HVOF and the HVAF Process". *Journal of Thermal Spray Technology*. **7** (2): 213–8.
Bibcode:1998JTST....7..213J (<https://ui.adsabs.harvard.edu/abs/1998JTST....7..213J>) .
doi:10.1361/105996398770350954 (<https://doi.org/10.1361%2F105996398770350954>) .
S2CID 135552046 (<https://api.semanticscholar.org/CorpusID:135552046>) .
15. Károly, Z.; Szépvölgyi, János (1 February 2005). "Plasma Spheroidization of Ceramic Particles". *Chemical Engineering and Processing*. **44** (2): 221–224. *doi:10.1016/j.cep.2004.02.015* (<https://doi.org/10.1016%2Fj.cep.2004.02.015>) .
16. Nerz, J.; B. Kushner; A. Rotolico (1992). "Microstructural evaluation of tungsten carbide-cobalt coatings". *Journal of Thermal Spray Technology*. **1** (2): 147–152. *Bibcode:1992JTST....1..147N* (<https://ui.adsabs.harvard.edu/abs/1992JTST....1..147N>) .
doi:10.1007/BF02659015 (<https://doi.org/10.1007%2FBF02659015>) . **S2CID 135907562** (<https://api.semanticscholar.org/CorpusID:135907562>) .
17. Nakajima, H.; Kudo, T.; Mizuno, N. (1999). "Reaction of Metal, Carbide, and Nitride of Tungsten with Hydrogen Peroxide Characterized by ^{183}W Nuclear Magnetic Resonance and Raman Spectroscopy". *Chemistry of Materials*. **11** (3): 691–697. *doi:10.1021/cm980544o* (<https://doi.org/10.1021%2Fcm980544o>) .
18. Kurlov, pp. 30, 135
19. Cafe, Kirt Blattenberger RF. "Velocity of Sound in Various Media" (<http://www.rfcafe.com/references/general/velocity-sound-media.htm>) . RF Cafe. Retrieved 4 April 2013.
20. Kittel, Charles (1995). *Introduction to Solid State Physics* (7th ed.). Wiley-India. **ISBN 81-265-1045-5**.
21. Ettmayer, Peter; Walter Lengauer (1994). *Carbides: transition metal solid state chemistry encyclopedia of inorganic chemistry*. John Wiley & Sons. **ISBN 0-471-93620-0**.
22. Sara, R. V. (1965). "Phase Equilibria in the System Tungsten–Carbon". *Journal of the American Ceramic Society*. **48** (5): 251–7. *doi:10.1111/j.1151-2916.1965.tb14731.x* (<https://doi.org/10.1111%2Fj.1151-2916.1965.tb14731.x>) .

23. Rudy, E.; F. Benesovsky (1962). "Untersuchungen im System Tantal-Wolfram-Kohlenstoff". *Monatshefte für Chemie*. **93** (3): 1176–95. doi:10.1007/BF01189609 (<https://doi.org/10.1007%2FBF01189609>)

24. Kleinhenz, Sven; Valérie Pfennig; Konrad Seppelt (1998). "Preparation and Structures of $[W(CH_3)_6]$, $[Re(CH_3)_6]$, $[Nb(CH_3)_6]^-$, and $[Ta(CH_3)_6]^-$ ". *Chemistry: A European Journal*. **4** (9): 1687–91. doi:10.1002/(SICI)1521-3765(19980904)4:9<1687::AID-CHEM1687>3.0.CO;2-R (<https://doi.org/10.1002%2F%28SICI%291521-3765%2819980904%294%3A9%3C1687%3A%3AAID-CHEM1687%3E3.0.CO%3B2-R>)

25. Sickafoose, S.M.; A.W. Smith; M. D. Morse (2002). "Optical spectroscopy of tungsten carbide (WC)". *J. Chem. Phys.* **116** (3): 993. Bibcode:2002JChPh.116..993S (<https://ui.adsabs.harvard.edu/abs/2002JChPh.116..993S>). doi:10.1063/1.1427068 (<https://doi.org/10.1063%2F1.1427068>)

26. Rao (2009). *Manufacturing Technology Vol.II 2E* (<https://books.google.com/books?id=3sS5a4jqzS8C&pg=PA30>). Tata McGraw-Hill Education. p. 30. ISBN 978-0-07-008769-9.

27. Davis, Joseph R., ASM International Handbook Committee (1995). *Tool materials* (https://books.google.com/books?id=Kws7x68r_aUC&pg=PA289). ASM International. p. 289. ISBN 978-0-87170-545-7.

28. Ford, Roger (2000). *Germany's Secret Weapons in World War II* (<https://books.google.com/books?id=IU8xBhe9ntsC&pg=PA125>). Zenith Imprint. p. 125. ISBN 978-0-7603-0847-9.

29. Zaloga, Steven J. (2005). *US Tank and Tank Destroyer Battalions in the ETO 1944–45* (<https://books.google.com/books?id=sCdlGIbmHjoC&pg=PA37>). Osprey Publishing. p. 37. ISBN 978-1-84176-798-7.

30. Green, Michael & Stewart, Greg (2005). *M1 Abrams at War* (https://books.google.com/books?id=M1P6jT8_yrgC&pg=PA66). Zenith Imprint. p. 66. ISBN 978-0-7603-2153-9.

31. Tucker, Spencer (2004). *Tanks: an illustrated history of their impact* (<https://books.google.com/books?id=N481TmqiSiUC&pg=PA348>). ABC-CLIO. p. 348. ISBN 978-1-57607-995-9.

32. "Oil and Gas Components" (<https://www.hyperionmt.com/products/Oil-Gas/>). Hyperion Materials & Technologies. Retrieved 21 June 2022.

33. Connally, Craig (2004). *The mountaineering handbook: modern tools and techniques that will take you to the top* (<https://books.google.com/books?id=c0MUESWJo2oC&pg=PA14>). McGraw-Hill Professional. p. 14. ISBN 978-0-07-143010-4.

34. Hermance, Richard (2006). *Snowmobile and ATV accident investigation and reconstruction* (<https://books.google.com/books?id=-msCn1jK8z8C&pg=PA13>). Lawyers & Judges Publishing Company. p. 13. ISBN 978-0-913875-02-5.

35. Hamp, Ron; Gorr, Eric & Cameron, Kevin (2011). *Four-Stroke Motocross and Off-Road Performance Handbook* (<https://books.google.com/books?id=24kHuJV2LcAC&pg=PA69>). MotorBooks International. p. 69. ISBN 978-0-7603-4000-4.

36. "Road nail" (https://web.archive.org/web/20120326173505/http://www.mustadhoofnails.com/subcat/40/product/1369/page/0/road_nail/). Mustad Hoof Nails. Archived from the original on 26 March 2012.

37. [Post-Graduate Foundation in Veterinary Science] (1997). *Farriery: a convention for farriers and veterinarians, in conjunction with AustralAsian Farrier News* (<https://books.google.it/books?hl=en&id=CGZWAAAAYAAJ>) . Sydney South, NSW: University of Sydney. Accessed March 2019.

38. Reichert, Marimargaret; Young, Jack H. (1997). *Sterilization technology for the health care facility* (<http://books.google.com/books?id=HDzcboqJR9kC&pg=PA30>) . Jones & Bartlett Learning. p. 30. ISBN 978-0-8342-0838-4.

39. "Tungsten Carbide Manufacturing" (<https://web.archive.org/web/20070304235856/http://www.forevermetals.com/jewelry-tungsten-carbide-ring/>) . forevermetals.com. Forever Metals. Archived from the original (<https://www.forevermetals.com/jewelry-tungsten-carbide-ring/>) on 4 March 2007. Retrieved 18 June 2005.

40. SERANITE – Trademark Details (<http://trademarks.justia.com/774/86/seranite-77486248.html>) Justia Trademark, 2013

41. "Breaking Tungsten Carbide" (<http://cherylkremkow.com/designer-jewelry/breaking-tungsten-carbide/>) . Cheryl Kremkow. 29 October 2009. Retrieved 29 October 2009.

42. Moser, A; Exadaktylos, A; Radke, A (2016). "Removal of a Tungsten Carbide Ring from the Finger of a Pregnant Patient: A Case Report Involving 2 Emergency Departments and the Internet" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4799811>) . Case Rep Emerg Med. **2016**: 8164524. doi:10.1155/2016/8164524 (<https://doi.org/10.1155%2F2016%2F8164524>) . PMC 4799811 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4799811>) . PMID 27042363 (<https://pubmed.ncbi.nlm.nih.gov/27042363>) .

43. "How does a ballpoint pen work?" (<http://science.howstuffworks.com/question683.htm>) . Engineering. HowStuffWorks. 1998–2007. Retrieved 16 November 2007.

44. "Wolfram Martin Simpson Signature Slide" (<http://www.wolframslides.com/mssig.php>) . Wolfram Slides. Retrieved 6 August 2013.

45. Levy, R. B.; M. Boudart (1973). "Platinum-Like Behavior of Tungsten Carbide in Surface Catalysis". Science. **181** (4099): 547–9. Bibcode:1973Sci...181..547L (<https://ui.adsabs.harvard.edu/abs/1973Sci...181..547L>) . doi:10.1126/science.181.4099.547 (<https://doi.org/10.1126%2Fscience.181.4099.547>) . PMID 17777803 (<https://pubmed.ncbi.nlm.nih.gov/17777803>) . S2CID 39638807 (<https://api.semanticscholar.org/CorpusID:39638807>) .

46. Rodrigues, J.A.J.; Cruz, G. M.; Bugli, G.; Boudart, M.; Djéga-Mariadassou, G. (1997). "Nitride and carbide of molybdenum and tungsten as substitutes of iridium for the catalysts used for space communication". Catalysis Letters. **45**: 1–2. doi:10.1023/A:1019059410876 (<https://doi.org/10.1023%2FA%3A1019059410876>) . S2CID 92178880 (<https://api.semanticscholar.org/CorpusID:92178880>) .

47. "Hard like Diamond" (<https://newsroom.porsche.com/en/christophorus/porsche-cayenne-turbo-surface-coated-brake-pscb-matthias-leber-weissach-14589.html>) . 14 December 2017. Retrieved 12 May 2018.

48. Sprince, NL.; Chamberlin, RI.; Hales, CA.; Weber, AL.; Kazemi, H. (1984). "Respiratory disease in tungsten carbide production workers". *Chest*. **86** (4): 549–557. doi:10.1378/chest.86.4.549 (<https://doi.org/10.1378%2Fchest.86.4.549>) . PMID 6434250 (<https://pubmed.ncbi.nlm.nih.gov/6434250>) .
49. "12th Report on Carcinogens" (<https://web.archive.org/web/20110625114247/http://ntp.niehs.nih.gov/go/roc12>) . National Toxicology Program. Archived from the original (<http://ntp.niehs.nih.gov/go/roc12>) on 25 June 2011. Retrieved 24 June 2011.

Cited sources

- Kurlov, Alexey S.; Gusev, Aleksandr I. (2013). *Tungsten Carbides: Structure, Properties and Application in Hardmetals* (<https://books.google.com/books?id=vcLBAAAAQBAJ&pg=PA3>) . Springer Science & Business Media. doi:10.1007/978-3-319-00524-9 (<https://doi.org/10.1007%2F978-3-319-00524-9>) . ISBN 978-3-319-00524-9. LCCN 2013942113 (<https://lccn.loc.gov/2013942113>) . S2CID 136700223 (<https://api.semanticscholar.org/CorpusID:136700223>) .

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- International Chemical Safety Card 1320 (<http://www.inchem.org/documents/icsc/icsc/eics1320.htm>)
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